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(71) Applicant: HONEYWELL INC. [US/US]; Honeywell Plaza, Minneapolis, MN 55408 (US).

(72) Inventors: CROOK, Thomas, M. ; 1489 23rd Avenue Northwest, New Brighton, MN 55112 (US). PODGORSKI, Theodore, J. ; 1764 Maryknoll Avenue, St. Paul, MN 55109 (US).

(74) Agent: CHAMPION, Ronald, E.; Honeywell Inc., Honeywell Plaza - MN12-8251, Minneapolis, MN 55408 (US).

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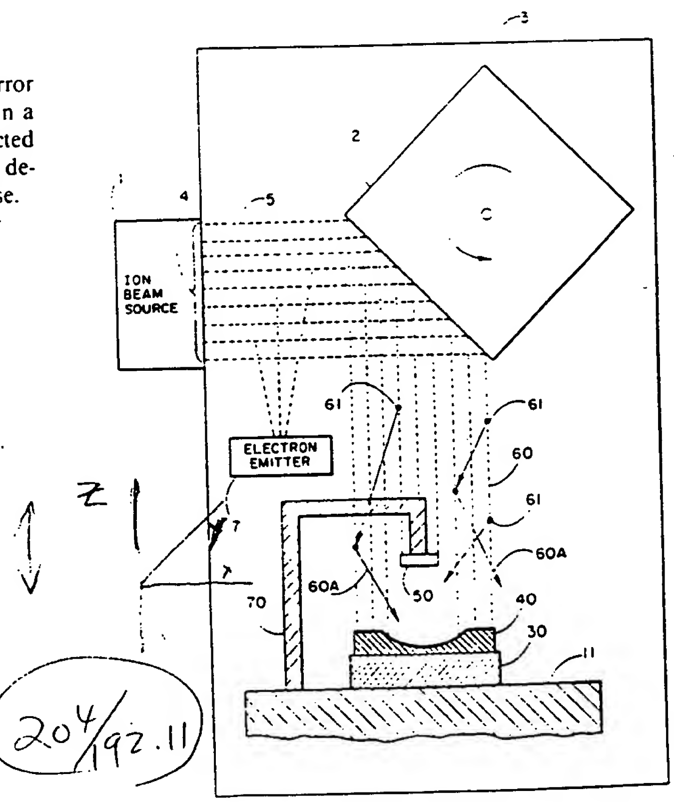
(54) Title: METHOD AND APPARATUS FOR CONCAVE SUBSTRATES

(57) Abstract

A method of fabricating a deposited concave mirror substrate includes adjusting the background pressure in a vacuum system and interposing a mask between a directed flow of deposition material and a flat base so that the deposition material forms a concave substrate on the base.



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METHOD AND APPARATUS FOR CONCAVE SUBSTRATES

BACKGROUND OF THE INVENTION

I. Field of th Inv ntion:

The present invention is related to producing deposited concave substrates used for ring laser gyro mirrors and, in particular, is directed to a method which uses a mask for forming a deposited concave substrate for a multilayer mirror assembly.

High performance ring laser gyros (sometimes referred to as RLGs) require optical cavities formed by highly reflecting, multi-layer mirrors. For high performance, all of the mirrors must possess low scattering behavior at the wavelength of laser light employed in such gyros. In addition, one or more of the cavity mirrors must provide a positive focusing of the laser beams in such ring laser gyros.

The current methods of obtaining low scatter, high reflectance ring laser gyro mirrors require depositing multiple quarter wavelength optical thickness layers of alternating refractive index materials onto very low scattering substrates, whose surfaces have been carefully polished to achieve nearly complete planarity. For the focusing mirror or mirrors, the conventional practice is to optically grind or polish an essentially spherical concavity into suitable substrates. Such a substrate 10 is shown in Figure 1. Then, as shown in Figure 2, a multi-layered, high reflectance mirror 20 is deposited onto the substrate, producing a curved mirror appropriate for the RLG cavity.

U.S. Patent No. 4,737,946 to Yamashita, et al., for example, shows a waveguide layer used for processing optical data wherein a concavity is formed by polishing or etching.

U.S. Patent 4,776,868 to Trotter, Jr., et al. shows the use of a mask in a vapor deposition process for preparing a lens or lens array. The mask is so positioned between the vapor source and the substrate that obscuration by the solid portions of the mask around a hole in the mask

In yet another aspect of the invention, the flow of deposition material emanates from an ion beam sputtering process.

In yet another aspect of the invention, the flow of deposition material may be produced by an electron beam deposition process or any other vapor deposition process.

Yet another advantage of the invention is that it provides a method for manufacturing a large number of concave substrates simultaneously.

Other objects, features and advantages of the present invention will become apparent to those skilled in the art through the Description of the Preferred Embodiment, Claims, and drawings herein wherein like numerals refer to like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a side view in cross section of a mirror substrate having a surface which includes a concave portion.

Figure 2 is a side view in cross section of a mirror substrate of the type shown in Figure 1 having a multi-layer mirror deposited on the substrate.

Figure 3 is a view in cross section which schematically shows one aspect of the invention whereby a concave deposit is deposited onto a flat substrate.

Figure 4 is a view in cross section of a multilayer mirror deposited on a concave mirror substrate made in accordance with the invention.

Figure 5 shows schematically one example apparatus used in the fabrication of a deposited concave mirror substrate.

Figures 6, 7 and 8 are graphs showing the relationships between mask separation and center thickness, radius of curvature and efficiency, respectively.

Figure 9 is a schematic diagram of one embodiment of the invention employing an ion beam deposition process to fabricate a deposited concave mirror substrate.

Silica based glasses such as fused silica, soda-limes silicate, and the like may also be used. Other materials, well known in the art, may also serve as a base substrate material.

Once the deposited curve mirror substrate is completed, multiple layers of optical films suitable for fabricating a ring laser gyroscope mirror may be deposited onto the concave mirror substrate. In order to deposit the mirror material, the mask is first removed and mirror material is deposited onto the concave mirror substrate in a manner as described herein using a suitable deposition process.

Referring now to Figure 4, a deposited concave mirror of the type suitable for use in a ring laser gyro is shown having been made by the process of the invention. The mirror comprises multilayer surfaces comprising multiple firm layers of at least two different materials 20 and 21. The multiple film layers 20, 21 may be comprised of alternating layers of optical materials having different indices of refraction. For example, in the case of a ring laser gyro mirror, the multiple film layers 20, 21 may comprise quarter wavelength thickness optical layers with indices of refraction greater than 2.0 alternating with optical layers having index of refraction less than 1.5. One example of a material having an index of refraction greater than 2.0 is titanium dioxide. One example of a material having an index of refraction of less than 1.5 is silicon dioxide. Zirconium dioxide may also be used as one of the alternating multiple film layers.

Referring now to Figure 5, an apparatus for fabricating a deposited curve substrate is shown, including a support 70, mask 50, concave mirror substrate deposit 40 and base 30. The support 70 may be selected to have as little profile as possible. If the dimensions of the support are too large, shadowing will occur under the support. This shadowing may result in a slight groove or channel in the deposited substrate in the area directly under the support indicated generally by reference numeral

deposition process is about 10^{-4} Torr, for example. The deposition thickness is a function of deposition rate and duration as is well known in the art. The separation parameter will be discussed immediately below with reference to Figures 6, 7, and 8. The mask diameter is directly related to the amount of surface area which is concave on the base. Making the support as small as possible and as far away from the base as possible while still maintaining rigidity is important in this process in order to eliminate or reduce the shadowing effect as discussed above. Higher background gas pressure will also reduce the shadowing effect.

Referring now to Figure 6, the relationship between the separation of the mask from the base 30 is shown in its relationship to center thickness of the substrate deposit. As shown by plot CT in Figure 6 at 0 distance separation from the substrate, the center of thickness is 0 because the mask is in contact with the substrate at that point substantially blocking all deposition material. As the mask is moved further and further away from the base, the center thickness approaches a maximum thickness, namely the thickness of the unmasked portion 44, as shown in Figure 5 of the base.

Figure 7 shows in curve RC the radius of curvature of the deposited substrate as it relates to separation of the mask from the base 30. In general, the mask is separated from the base by a distance equivalent to the diameter of the mask, in the case of a circular mask, for example. Therefore, in one example having a .2 inch diameter piece of rod serving a mask, the separation from the base typically may be about .2 inches. Using such a mask, the resulting radius of curvature can be advantageously made in the range of 2.5 - 5 meters depending upon the background gas pressure, the rate of deposition and the time of exposure of the base to the directed flow of deposition. As those skilled in the art will appreciate, a longer deposition duration at a predetermined rate will increase the thickness and the radius developed is inversely

such as dielectrics or when semi-conductor materials are sputtered.

The ion beam source 1 emits an ion 5 directed at the target 2. The atmosphere within the ion beam source is controlled to provide sufficient gas to sustain a discharge which generates ion beam 5. Ion beam 5 impacts target 2 which may be a rotatable multi-target assembly for use in applying more than one material in the same vacuum cycle. That is, each face of the target 2 may be a different material. A multilayer concave mirror substrate may be fabricated by rotating the target in a well known manner and using appropriate, alternating target materials on the faces of target 2. The impacted target area provides a source of sputtered target material which sputters in all directions forward of the target. The sputtered target material bombards base 30. However, a portion of base 30 is partially blocked by mask 50, although some sputter material is still deposited under the area covered by mask 50 because of molecular scattering of sputtered material by the background gas 61 and divergence of the sputtered beam. By controlling the size and shape of the mask 50 as explained herein, a concave mirror substrate 40 is formed on base 30. The target materials may be comprised of materials as indicated above such as zirconium dioxide, silicon dioxide, titanium dioxide or any other materials or combination of target materials suitable for use as a concave substrate. Once the concave substrate 40 is formed, the mask 50 may be removed from in front of the substrate and multilayer optical films may be deposited for form, for example, ring laser gyro mirrors, on the concave substrate 40 using the same sputtering method and apparatus.

Those skilled in the art will recognize that large numbers of concave substrates can be manufactured simultaneously in the same deposition chamber limited only by the size of the chamber and holding fixtures. In this way the invention provides a method for manufacturing a large number of concave substrates simultaneously.

CLAIMS

1. A method of fabricating a concave deposited substrate comprising:

(a) interposing a mask between a source of deposition material and a base;

(b) controlling the background gas pressure between the source and the base to help form the concave substrate; and

(c) bombarding the base with deposition material wherein the mask is located to block a portion of the deposition material so that the deposition material forms a concave substrate on the base.

2. The method of Claim 1 further comprising the steps of:

(a) removing the mask; and

(b) depositing multiple film layers of at least two different materials onto the concave substrate to form the mirror.

3. The method of Claim 2 wherein the multiple film layers comprise a plurality of optical film layers having at least two different indices of refraction.

4. The method of Claim 3 wherein the plurality of optical film layers comprise a first group of optical film layers having an index of refraction greater than 2.0, and a second group of optical film layers having an index of refraction less than 1.5, wherein the first and second groups are deposited in alternating layers and each layer is a quarter wavelength optical thickness.

5. The method of Claim 4 wherein the first group of optical layers are substantially comprised of titanium dioxide.

6. The method of Claim 4 wherein the second group of optical layers are substantially comprised of silicon dioxide.

15. The apparatus of Claim 14 further including multiple film layers of at least two different materials formed on the deposited substrate layer.

16. The apparatus of Claim 15 wherein the base deposited concave substrate layer and multiple film layers form a mirror.

17. The apparatus of Claim 16 wherein the multiple film layers comprise alternating quarter wavelength optical layers having at least two different indices of refraction.

18. A method of fabricating a multilayer deposited concave mirror substrate on a flat base comprising:

(a) operating an ion beam source to alternately sputter a first target material and a second target material so as to alternately produce directed flows of sputtered first target material and sputtered second target material so as to form alternating layers of first and second target materials on the flat base;

(b) controlling the background gas pressure between the source and the base to help form the multilayer concave substrate; and

(c) interposing a mask between the flow of alternately sputtered first and second target materials and the flat base wherein the mask partially blocks the first and second sputtered target materials from directly bombarding a central portion of the base so as to form a multilayer concave mirror substrate on the central portion.

19. The method of Claim 18 further comprising the steps of:

(d) removing the mask; and

(e) operating the ion beam source to alternately sputter a third and fourth material so as to alternately produce directed flows of sputtered third target material and sputtered fourth target material onto the multilayer concave mirror substrate wherein the third and fourth target materials form a multilayer mirror covering the multilayer concave mirror substrate.

Fig.-1 (PRIOR ART)

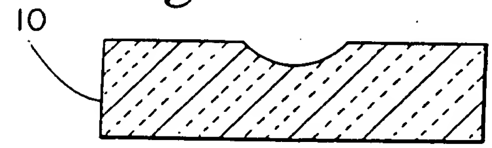

Fig.-2 (PRIOR ART)

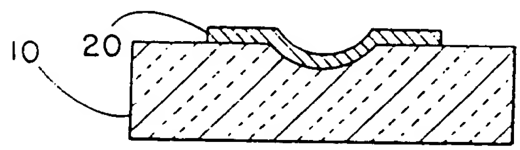

Fig.-3

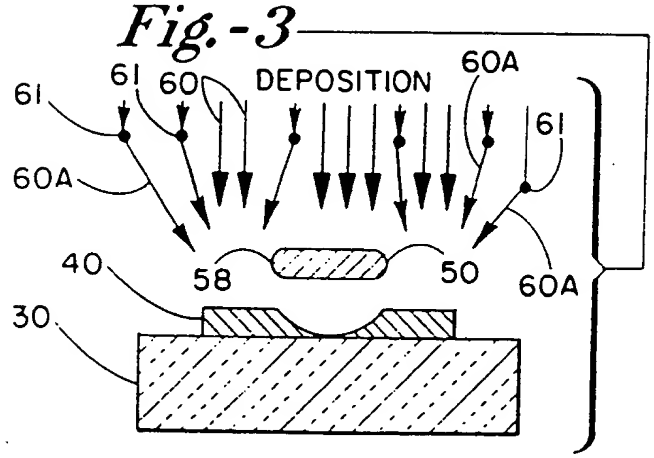

Fig.-4

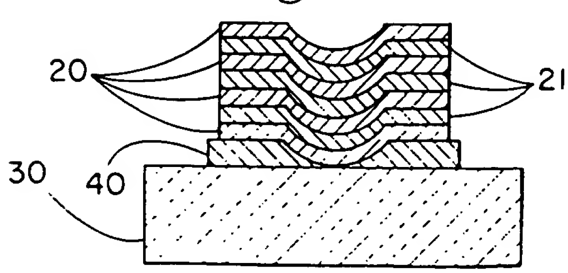

Fig.-5

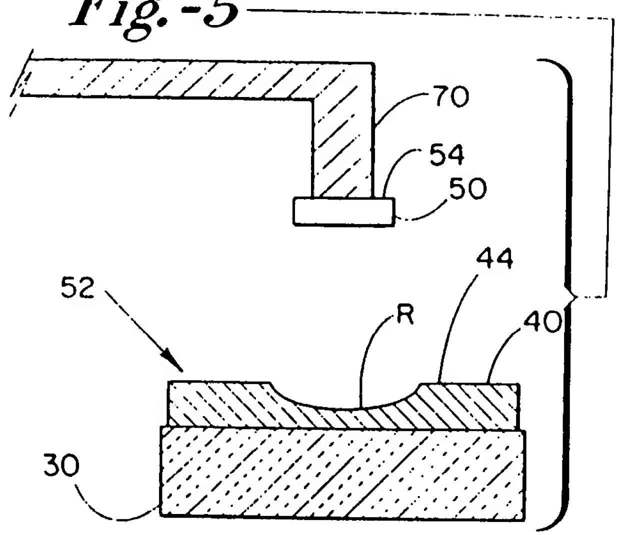

Fig.-6

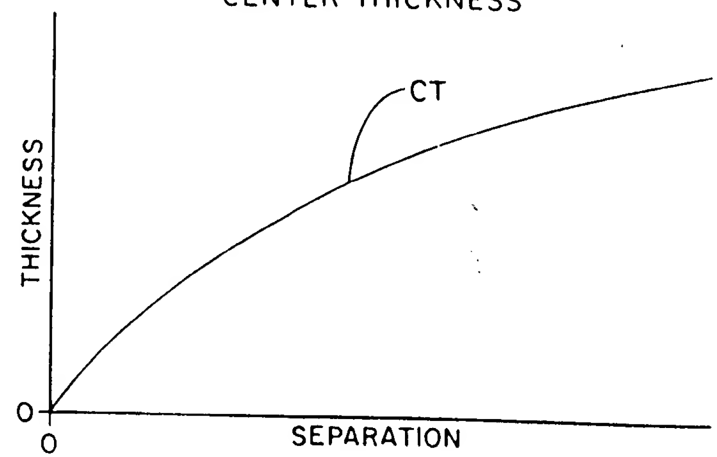

Fig.-7

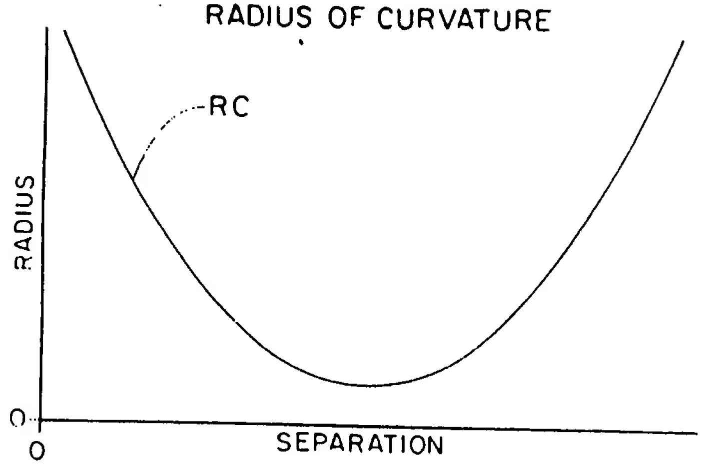

Fig.-8

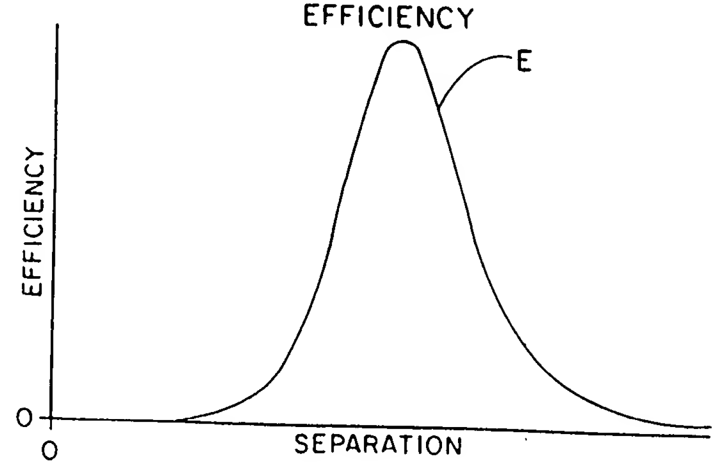

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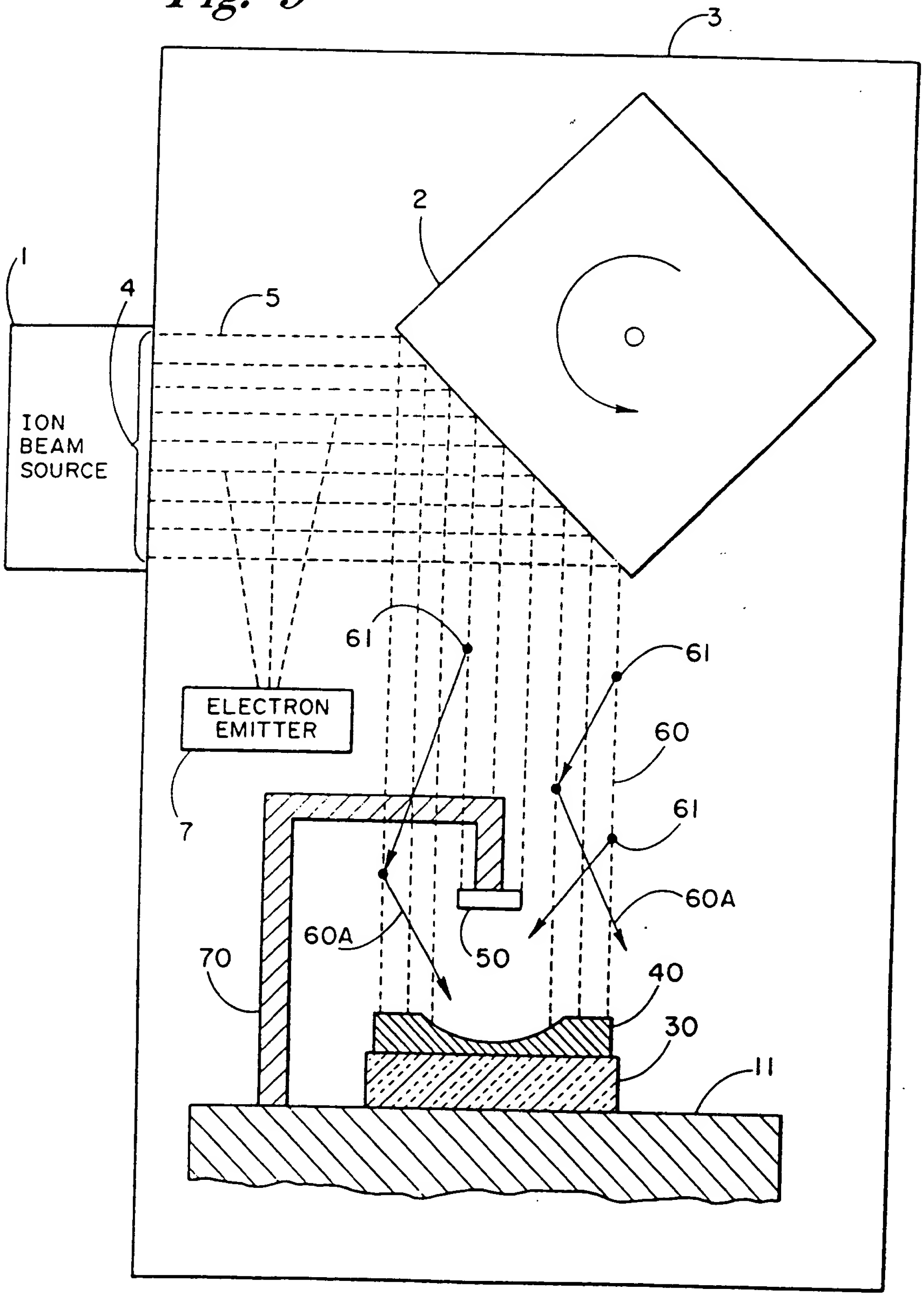
Fig.-9



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